

Status of the T2K long baseline neutrino oscillation experiment

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Abstract. The T2K experiment is a long baseline neutrino oscillation experiment. The main goals of the experiment are a measurement of the neutrino mixing angle θ_{13} by the observation of electron neutrino appearance and a precise measurement of θ_{23} and mass difference by the observation of muon neutrino disappearance. Construction of the neutrino beamline has recently been completed; production of the first neutrino beam was confirmed by observing muons produced by the proton beam. In this paper, the T2K physics goals and the status of preparations toward the start of the experiment in fall 2009 are reported.

1. Physics goals of the T2K experiment

The T2K experiment is a long baseline neutrino oscillation experiment. A muon neutrino beam of sub GeV energy is produced using a high intensity proton accelerator complex, J-PARC at Tokai village, Japan. Then, after traveling 295 km, it is measured at a gigantic water Čerenkov detector, Super-Kamiokande, at Kamioka, Japan. Figure 1 shows the baseline of the experiment.

In the three generations framework, the neutrino oscillation probability for this energy region and this baseline length is written as

$$P_{\mu \rightarrow x} \approx 1 - \cos^4 \theta_{13} \sin^2 \theta_{23} \sin^2(1.27 \Delta m_{23}^2 L / E_\nu)$$

for ν_μ disappearance, and

$$P_{\mu \rightarrow e} \approx \sin^2 \theta_{23} \sin^2 2\theta_{13} \sin^2(1.27 \Delta m_{13}^2 L / E_\nu)$$

for ν_μ to ν_e appearance, where $L = 295$ km and E_ν is a neutrino energy (GeV).

The main physics motivation of the T2K experiment comprises three goals.

- (i) Discovery of $\nu_\mu \rightarrow \nu_e$

Among three mixing angles, only θ_{13} is unknown and set an upper limit[1]. In the T2K experiment, θ_{13} can be explored by searching for the $\nu_\mu \rightarrow \nu_e$ appearance signal. The ν_e signals are identified from the distinctive quantity of observed Čerenkov rings and reconstructed neutrino energy. The sensitivity is $\sin^2 2\theta_{13} = 0.006$ at 90% C.L. This represents an order of magnitude improvement over the current limit.

- (ii) Precision measurements of oscillation parameters in ν_μ disappearance.
 The goal is an observation of the oscillation minimum, a 1% measurement of the mixing angle and a 10% measurement of $|\Delta m^2|$ ($\delta(\Delta m_{23}^2) = 10^{-4} \text{ eV}^2$ and $\delta(\sin^2 2\theta_{23}) = 0.01$).
- (iii) Search for sterile components in ν_μ disappearance by detecting the neutral-current events.

In order to achieve these goals, T2K will accumulate data with 3.75 MW.yr integrated beam power of J-PARC, which corresponds to 5 years of running with the design beam power of 0.75 MW.

With the successful achievement of these measurements, the construction of more than 100 kt far detectors, and a possible upgrade of the accelerator from 0.75 MW to a few MW in beam power, further experiments can be envisaged. These include a sensitive search for the CP violation in the lepton sector (CP phase δ down to $10^\circ \sim 20^\circ$).

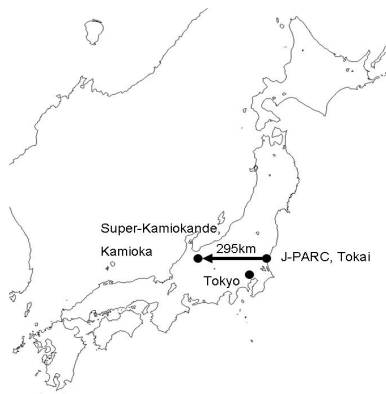


Figure 1. Baseline of the T2K experiment.

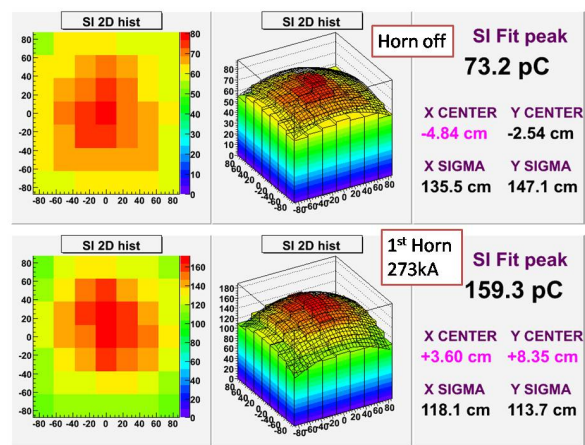


Figure 2. Muon flux measured by MUMON Silicon PIN photodiode. Top figure : muon profile when all the horns are off. Bottom figure : muon profile when the 1st horns are operated with 273 kA.

2. Overview of the Experiment

The far detector, Super-Kamiokande, located in the Kamioka Observatory, Institute for Cosmic Ray Research (ICRR), University of Tokyo, has been successfully taking data since 1996.

It is a 50,000 ton water Čerenkov detector located at a depth of 2,700 meters water equivalent in the Kamioka mine in Japan. Its performance and results in atmospheric neutrinos and solar neutrinos have been well-documented in [3]. The total fiducial mass is 22,500 ton.

Photons from the Čerenkov rings produced by relativistic charged particles are detected by PMT's. Their pulse-height and timing information are fitted to reconstruct the vertex, direction, energy, and particle identification. The Čerenkov ring shape, clear ring for muons and fuzzy ring for electrons, provides good e/μ identification.

A ν_μ beam at J-PARC is produced from the decay of pions produced by protons hitting a target. The pions are focused by magnets called electromagnetic horns into a volume where they decay in flight. The beam consists of almost pure ν_μ s.

A key element of the design of the T2K facility is that the neutrino beam is directed so that the beam axis actually misses Super-Kamiokande. This off-axis neutrino beam technique is

described in Ref.[2]. Due to the kinematics of the pion decay, pions in a wide momentum range contribute to a narrow energy range of neutrinos. This results in a considerable improvement in the quality of the beam for the ν_e appearance experiment. The peak neutrino energy can be adjusted by choosing the off-axis angle. The J-PARC neutrino facility is capable of producing a beam whose off-axis angle is from 2.0 degree to 2.5 degree. The peak energy is 500 ~ 700 MeV and corresponds to $\Delta m_{23}^2 = 2 \sim 3 \times 10^{-3} \text{ eV}^2$ for the baseline length of 295 km. Contamination of ν_e in the beam, which is a background for the ν_e appearance search, is expected to be 0.2% at the peak energy.

At J-PARC, primary protons are first accelerated by the LINAC and then by Rapid Cycle Synchrotron up to 3 GeV and by the Main Ring synchrotron (MR) up to 30 GeV. A 30 GeV proton beam is extracted from the MR in a single turn to the neutrino facility. The primary proton beamline of the neutrino facility transfers the proton beam from the MR to the neutrino production target. It consists of normal conducting magnets and super-conducting combined-function type magnets. The neutrino production target is a graphite rod of 26 mm diameter and 90 cm length. The 3 magnetic horns are driven by a pulsed current of 320 kA at peak synchronized with the proton beam timing. The decay volume (DV) is a free space down stream of the horns where pions decay in flight into ν_μ 's and muons. A beam dump is placed at the end of DV, 110m from the target. Muon monitors (MUMON) is placed just behind the beam dump to measure the muon flux. While almost all hadrons are absorbed by the beam dump, muons of energy > 5 GeV can penetrate the beam dump. MUMON provides pulse-by-pulse information on the intensity and profile (direction) of the beam.

At 280 m from the target, neutrino detectors are placed in order to measure the properties of neutrinos just after their production. Details of these near detectors are described in Ref.[4].

3. Present status

Super-Kamiokande has been running steadily after the renewal of the readout electronics in 2008.

The construction of the J-PARC accelerator complex was completed in 2008 and the beamline of the neutrino facility in Mar. 2009. On 23rd April 2009, the first proton beam was extracted to the neutrino beamline and MUMON observed the muon signal confirming the generation of neutrinos. The beamline magnets and proton beam monitors worked as expected. Only the first horn was excited and its focusing effect was confirmed by the measurement of the muon profile with MUMON as shown in Fig.2. The nominal intensity during this commissioning run was $\sim 4 \times 10^{11}$ protons per spill, which is $\sim 0.1\%$ of the design intensity. From Autumn 2009, further commissioning is planned to increase the beam intensity and all 3 horns will be excited. First physics data taking is expected to begin in 2010.

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